Soils and Foundations 2012;52(4):668–681

The Japanese Geotechnical Society

Soils and Foundations

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On the compression behaviour of reconstituted soils

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Received 31 October 2011; received in revised form 12 May 2012; accepted 19 June 2012
Available online 7 September 2012

Abstract

Transitional behaviour has been recognised in a diverse range of soils in the literature to date, from gap-graded soils to well-graded silts and sands. It is typified by non-convergent compression paths and critical state lines that are non-unique and which are dependent on the initial sample density. Many soil mechanics theories assume soils to have unique normal compression and/or critical state lines, which is not the case for a transitional soil. For such a soil it would therefore be difficult to identify the effects of structure on the mechanics since there is no unique behaviour of the soil when reconstituted. This paper describes series of oedometer tests that were performed to investigate in more detail when and why non-convergent compression behaviour might be expected, as a first step to identifying which soils are transitional. The effects of mixing soils of different grain sizes and mineralogies were explored, the tests revealing that convergent or non-convergent behaviour could be brought about either by relatively small changes to the proportions of the soil particles or by changes to their nature. It was also found that in some soils with non-convergent compression behaviour there was particle breakage while in others there was not. Since the factors that influence the mode of compression behaviour were found to be complex, it is concluded that each new soil encountered must be assessed individually for whether it is transitional, and that the accuracy of void ratio measurements is of particular importance in establishing this reliably.

Keywords: Compression; Particle breakage; Void ratio; Sandy soil; Artificially mixed soils; Laboratory tests

1. Introduction

Over the past two decades research in soil mechanics has shown that the behaviour of many clean sands can be described within a critical state framework similar to that for clays (e.g., Been and Jefferies, 1985; Coop and Lee, 1993; McDowell and Bolton, 1998). The main difference between the frameworks for sands and clays is the mechanism of plastic volumetric compression. In clays physical-chemical forces between the particles control the behaviour whereas in coarse grained soils the stresses are transmitted through inter-particle contacts in strong force chains that result in particle breakage if the applied stresses are sufficiently large. Another key difference is that sands are deposited at much denser states than clays, and so as they are compressed to higher stresses they may meet a unique Normal Compression Line (NCL) in v:logσ'_v or v:lnp' space (v, specific volume; σ'_v, vertical effective stress; p', mean normal effective stress) (Coop and Lee, 1993; McDowell and Bolton, 1998; Pestana and Whittle, 1995). The increase of gradient or "knee" point in the compression paths as they reach the NCL is generally believed to correspond to the onset of major particle damage and can be correlated with the strength of individual particles (e.g., Kwag et al., 1999), although it is not the true onset of plastic strains. The specific volume and stress level at which the compression paths reach

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Peer review under responsibility of The Japanese Geotechnical Society.

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http://dx.doi.org/10.1016/j.sandf.2012.07.008

a unique NCL will also depend on the initial density of the sand because of the effect that has on the coordination number. It is therefore typical that clean quartz sands reach their NCL at specific volumes in the range 1.3–1.6 and at stress levels typically of 10–100 MPa (e.g., Mesri and Vardhanabhuti, 2009). In contrast other sands with higher volumes and weaker particles can reach their NCLs at much lower stresses. For example the Dogs Bay carbonate sand tested by Coop and Lee (1993) reached its NCL at specific volumes in the region of 2.2–2.6 and at stresses in the range 1–3 MPa.

More recent research has identified that there are many intermediate graded soils which have behaviour that cannot be described within a simple critical state framework. These soils have been called 'transitional' in that they have a grading and a mode of behaviour between that of clean sands and plastic clays. The main feature of transitional soil behaviour is that unique normal compression and critical state lines cannot be identified (e.g., Martins et al., 2001; Ferreira and Bica, 2006; Nocilla et al., 2006). The compression paths of all soils must eventually become asymptotic to the minimum specific volume of 1 and in this sense they must all eventually converge. For data of Ferreira and Bica (2006) this must be beyond the maximum stress they used of about 25 MPa, but between this stress level and the possible locations of the horizontal asymptotes, it did not seem likely that there could exist a unique NCL since the void ratios had already reduced to very low values in the region of 0.2 at 25 MPa. Further aspects of the conventional critical state framework also break down for their shearing behaviour, such as the existence of unique State Boundary Surfaces (Nocilla et al., 2006).

Unfortunately, the term 'transitional' has already been used to describe two other aspects of soil behaviour, firstly an intermediate shearing mode between turbulent particle motion and sliding at the residual state (Lupini et al., 1981) and secondly the transitional or limiting fines content when soil behaviour changes from coarse grained to fine grained dominated (e.g., Pitman et al., 1994; Lade and Yamamuro, 1997; Yang et al., 2006). As yet it is unclear exactly how each definition is related. The type of behaviour associated with the most recent use of 'transitional', of concern in this paper, was first identified in gap-graded soils and was initially thought to be a feature exclusive to their behaviour. Martins et al. (2001) identified non-convergent compression behaviour for the gap-graded Botucatu residual sandstone. Ferreira and Bica (2006) confirmed that even if the compression was taken to very high stresses (25 MPa), convergence still could not be found and also that the location of the critical state line of the reconstituted soil was similarly dependent on the initial density, so that the soil might be defined as transitional. Critical states were defined to be those states of constant stress and volume at large strains in a triaxial apparatus, although it was realised that the non-unique volumes would mean that the fabric was not unique at that state.

Non-convergent compression paths were also found for a mixture of kaolin and a quartz sand (Fig. 1), which replicated the grading but with a simpler mineralogy. However, as

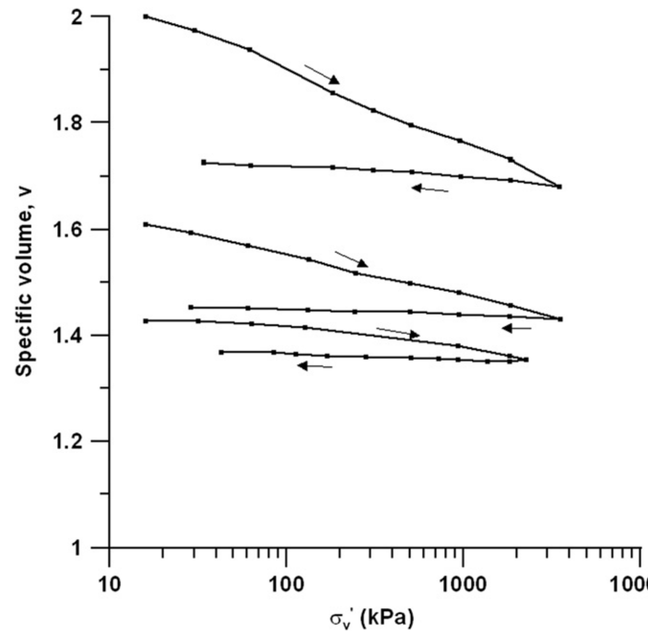

Fig. 1. One-dimensional compression paths of a model quartz sand–kaolin mixture containing 75% sand and 25% kaolin (redrawn from Martins et al., 2001).

further research was conducted, it was realised that this type of behaviour was likely also to be applicable to many intermediate graded soils (Nocilla et al., 2006), challenging a common assumption that most or all soils can be described within a critical state framework. Nocilla et al. (2006) searched for transitional behaviour in a well-graded Italian river silt, for which the clay content was controlled. As the clay content reduced the behaviour changed from that of a typical clay mode, with unique NCLs and CSLs, to a transitional one with non-unique NCLs and CSLs. Nocilla and Coop (2008) observed features of transitional behaviour in natural samples of the same well-graded silt, confirming that the transitional behaviour they had observed was not simply a function of the reconstituted fabrics created in the laboratory. More recently, Altuhafi and Coop (2011) have found that as they changed the grading of three sands of different mineralogies from poorly to well-graded, their compression behaviour changed from a "sand" type with a unique NCL associated with particle breakage, to a non-convergent one where there was no unique NCL. In each case when the non-convergent behaviour was observed there was no measurable breakage during compression, even up to 100 MPa.

The work described in the paper presents a new series of oedometer tests and particle size analyses that were conducted to investigate the role of grading, mineralogy and particle breakage in the compression of a wide variety of reconstituted soils. Various combinations of fine and coarse particles were used to create different soils to help identify which types of soil display non-convergent behaviour behaviour and to try to understand how the different particle types can influence the compression and particle breakage behaviour. Non-convergent compression behaviour may be seen as a first step in identifying transitional